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Standalone Solar Power System for Small and Medium Scale Enterprises (SMES) in Nigeria: Design and Economic Analysis

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ABSTRACT: One of the challenges facing small and medium scale enterprises in Nigeria is erratic nature of power supply. Most SMEs augment the power supply with gasoline generator with the believe that it is cheaper. As an alternative, a standalone solar power system is suggested. The results of technical and economic analysis of standalone solar power system carried out for an average barbing saloon outfit in Nigeria is presented in this work. With an assumed power of 409W and energy of 1750Whr/day for an average barbing saloon, the design arrived at 1kVA inverter, 3 nos 12V, 200AH battery, two units of 250W PV module and a 12V, 30A Charge controller. Using a life cycle cost analysis, the solar system gave a cost of N 404,881.4 while a 1kVA gasoline generator resulted to N527,563.53 over a life cycle of 5 years. The paper concludes that though initial cost of gasoline generator is cheap, solar system saves cost in the long run in addition to clean nature of the power supply and thus it is recommended for use by barbing saloon in Nigeria.
KEYWORDS: Solar, SMEs, Gasoline Generator, Life Cycle Cost.

I. INTRODUCTION

The unemployment rate in Nigeria is high and it is one of critical problems the country is still struggling to proffer solution to [13], emphasis is now being laid on vocational studies in schools and colleges with a view to ensuring that graduates are self-employed. Vocational skill acquisition like Barbing, Hair Dressing, Shoe Making, Fashion Designing etc are introduced for students to make choice and upon graduation, it is hoped that graduates will jettison the idea of searching for seemingly unavailable white-collar jobs and take-up already learnt vocational skill. These vocational skills, learnt by graduates as well as non-educated individuals constitute bulk of Small and Medium Scale Enterprises of the country. [3] and [12] reported that about 90% of the business ventures operating in Nigeria as a country can be referred to as small and medium scale enterprises (SMEs). SMEs in Nigeria is being confronted with a lot of challenges. Prominent among these challenges is inadequate, inefficient, and at times, non-functional infrastructural facilities, notably electricity supply, which tend to increase costs of operation as SMEs are forced to resort to private provisioning of utilities. This, undoubtedly has hindered the SMEs from making the desired impact on the economy of the country.

Electricity remains a prime mover that drives economic development of any nation. There is an extreme electricity deficiency in Nigeria and the causes of this deficiency are related to financial, socio-political, and structural issues. There is an 80% demand/supply gap of electricity in Nigeria and as a result most businesses generate power to meet their electricity requirement. One needs not contend the description of Nigeria economy by commentators on the power sector as a generator economy because of the enormous amount of off-grid electricity being generated to satisfy its power requirements [14]. Most SMEs in the country use gasoline generating set to augment insufficient and epileptic supply provided by the utility company. These generating sets pose great environmental hazard that is capable of causing serious health challenges. Renewable energy has been identified in [11] and [15] as one of the alternative solutions to Nigeria energy crisis. The sun, which is believed to be the greatest and abundant energy source among the renewable energy sources is readily available for use and the use of solar panel to convert the solar energy of the sun into the electrical usage has been believed to be the best alternative for renewable and growing energy. It is reported in [2] that Nigeria, with land area of $924 \times 10^3 \text{km}^2$ at an average of

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$5.535\,\mathrm{kWh/m^2/day}$has an average of $1.804\times10^{15}\,\mathrm{kWh}$ of incident solar energy annually. According to [4], 0.1% of this annual average solar energy at efficiency of 1% is capable of meeting energy demand of Nigeria. Despite the abundance of solar energy, most SMEs still use gasoline powered generating set to augment electric supply from the mains. The reason for this is not far-fetched and it is because most operators of SMEs believe solar system is costly. Hence in this work, technical and economic analysis of a stand-alone solar system was carried out, compared with that gasoline generator and conclusion drawn.

The block diagram of a standalone PV system is shown in figure 1. A PV panel (or PV array) is used to charge a battery through a charge controller. The dc output of the battery is converted to an ac source using inverter to power ac loads. In this paper, technical details of components sizing of the system for an average barbing salon outfit in Nigeria- being a SME, is considered. The Solar PV system is compared with a gasoline generator economically to ascertain its economic viability.

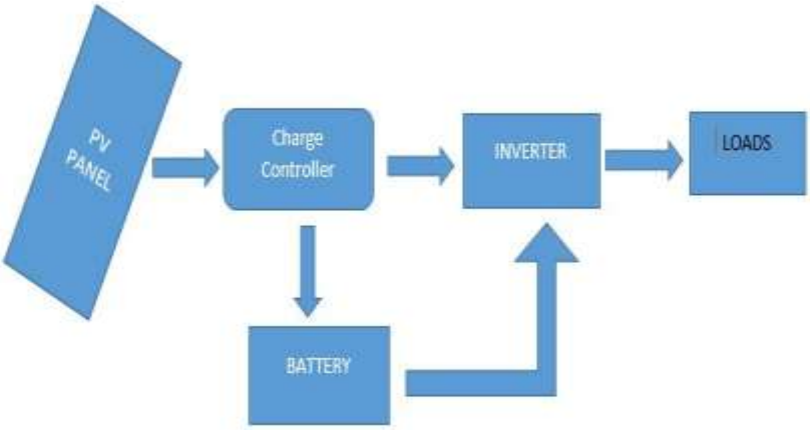

Figure 1: Block Diagram of a Stand-Alone Solar PV System

II. TECHNICAL ANALYSIS

Load Determination

In an average barbing salon outfit in Nigeria, the loads that can be found are lightings, clippers, fan, sterilizer, TV set and other miscellaneous loads. In this work, 3 nos CFL of rating 18W each, 2 nos Clippers each rated 15W, 1 no sterilizer of 50W, a standing fan rated 125W, 100W TV set and 50W miscellaneous loads are assumed.

Inverter Sizing

The choice of inverter should be in such a manner that the maximum expected ac loads power of the system will be handled safely. In some cases, selection is done to be able to cater for future load projection. Mostly a value of 20-30% future load projection factor is used to cater for future load expansion [10] and [16]. To get the size of the inverter in VA or kVA, power equation of equation 1 is used.

$$\mathrm{kVArating} = \frac{P}{1000\times\cos\theta} \qquad (1)$$

Where

P Power rating (W)

cosθ Power factor

Battery Sizing

The size of the battery required for the system, as obtained from [8] is given by equation (2):

$$\mathrm{BatteryAh} = \frac{\mathrm{Total\ Whr\ /day} \times \mathrm{DOA}}{\mathrm{Batterylossfactor} \times \mathrm{DOD} \times \mathrm{BatteryNominalVoltage}} \qquad (2)$$

Where:

DOD Battery Depth of Discharge

DOA System Day of Autonomy

Panel Array Sizing

The power required of the Photovoltaics Array for the system is designed using equation adopted from [1] and [10]. The equation is presented in equation (3):

$$P_{PV} = \frac{E_L}{\eta_{out} \times \eta_{cable} \times \eta_{reg}} \qquad (3)$$

$$\eta_{out} = \eta_B \times \eta_{Inv} \qquad (4)$$

The peak power of the PV array at the Peak Solar Hour (PSH) for a particular area is thus given by equation (5) [5]:

$$\text{PVPeakPower} = \frac{P_{pv}}{PSH} \quad (5)$$

Thus, the number of panels required for the system will be:

$$N_p = \frac{\text{PVPeakPower}}{P} \quad (6)$$

Where:

E_L Average Daily Load Demand (Whr/day)
P_{pv} Power Required of PV Array (W)
P Input Power of the PV Module
N_p Number of PV modules
η_{PV} PV efficiency
η_B Battery Efficiency
η_{Inv} Inverter Efficiency and
η_{cable} Cable Efficiency
η_{reg} Regulator Efficiency

Charge Controller Sizing

The choice of controller is concerned with safe charging of the battery to ensure the battery is not over or under charged. The controller, in addition, should be able to withstand the short circuit current coming from the photovoltaic modules. Usually, allowance of 20-30% is provided to cater for unforeseen circumstances. Hence, as presented in [6] and [7]:

$$\text{ControllerRating}(A) = N_{pp} \times 1.3 \times I_{sc} \quad (7)$$

Where:

N_{pp} Number of PV panel in parallel
I_{sc} PV Panel rated Short Circuit Current (A)

III. ECONOMIC ANALYSIS

Economy feasibility of any project is of utmost important. Though, a Solar PV system provides clean source of energy with relatively high reliability owing to ready availability of the source when compared with energy supplied by Nigeria utility company which is mainly from hydro and thermal plants. Despite this, its economic considerations should be looked into. Method of Life Cycle Costing presented in [9] is employed to determine the total life costs of the designed stand-alone solar system and power generating set- which is the most employed alternative energy source in use in Nigeria SMEs, for the considered case study- Barbing Salon.

The life cycle cost of an item consists of the total cost of owning and operating an item over its lifetime [9].

Before presenting the expressions for Life Cycle Cost (LCC), definitions of some terms are in other. These definitions can be found in [9].

Inflation rate (i)

This is the measure of decline in the value of money. If the rate of inflation is 100i% per annum, it implies that the purchasing power of money would have dropped by 100i% after a year. Assuming the cost of an item at present is x naira. In n years' time, if the inflation rate is 100i%. the cost of the item will be:

$$x(n) = x(i+1)^n \quad (8)$$

Discount rate (d)

This is the amount that can be realized on principal save or capital invested. If y Naira is invested in an investment at the discount rate of 100d%. after n years, the value of the investment will be:

$$y(n) = y(d+1)^n \quad (9)$$

Present Worth Factor (PW| |f)

If x=y, the ratio of x(n) to y(n) gives a dimensionless quantity known as Present Worth Factor.

$$PW_f = \frac{(i+1)^n}{(d+1)^n} \quad (10)$$

Present Worth

The present worth of an item is defined as the amount of money that would need to be invested at the present time with a return of 100d% in order to be able to purchase the item at a future time, assuming an inflation rate of 100i%. it is expressed mathematically as:

$$PW = PW_f(C_o) \quad (11)$$

For a recurring expense, such as fuel cost, the present worth is determined using:

$$PW = C_0\left[1 + \left(\frac{1+i}{1+d}\right) + \left(\frac{1+i}{1+d}\right)^2 + \left(\frac{1+i}{1+d}\right)^3 + \right.$$
$$\ldots 1+i1+dn-1 \quad (12)$$

$$\text{let } \left(\frac{1+i}{1+d}\right) = \beta, \quad (13)$$

then

$$PW = C_0[1 + \beta + \beta^2 + \beta^3 + \cdots \beta^{n-1}] \quad (14)$$

The term in the bracket is known as cumulative present worth factor CPW_f.

Upon simplifying equation (14) by bearing in mind that:

$$\sum_{m=0}^{\infty} \beta^m = \frac{1}{1-\beta} = 1 + \beta + \beta^2 + \beta^3 + \cdots \beta^{n-1} + \sum_{m=n}^{\infty} \beta^m \quad (15)$$

Hence,

$$CPW_f = \frac{1-\beta^n}{1-\beta} \quad (16)$$

And finally,

$$PW = CPW_f(C_o) \quad (17)$$

Once the PW is known for all cost categories relating to the purchase, maintenance and operation of an item, the life cycle cost (LCC) is defined as the sum of the PWs of all the components. The life cycle cost may contain elements pertaining to original purchase price, replacement prices of components, maintenance costs, fuel and/or operation costs, and salvage costs or salvage revenues. Calculating the LCC of an item provides important information for use in the process of deciding which choice is the most economical.

In this work, the life cycle cost of designed solar system is compared with that of a gasoline generating set employed to power the same set of loads.

IV. RESULTS AND DISCUSSION

Technical Analysis

The summary of loads, wattage ratings of each of the loads as well as the daily hours of operation of the loads for an average barbing salon outfit in Nigeria is presented in table 1. The total load estimated is 409W while the total Watt-hour per day is 1750Whr/day

Table 1: Load data for an average Barbing Salon in Nigeria

Appliances	Number	Watts Rating (W)	Daily Working Hours (hr)	Total Loads (Whr/day)
Clipper	2	15	6	180
CFL lights	3	18	5	270
Standing Fan	1	125	6	750
TV set	1	100	4	400
Sterilizer	1	50	1	50
Miscellaneous	-	50	2	100
Total				1750

From the estimated load data, the size of inverter required for the system is determined using equation (1) having allowed for 20% possible future load growth.
Allowing for 20% of the power gives:

$$P = 1.2 \times 409 = 490.8W$$

Using (1) and assuming a power factor of 0.8

$$kVArating = \frac{P}{1000 \times \cos\theta} = \frac{490.8}{1000 \times 0.8} = 0.6135kVA$$

A 1kVA pure wave sine inverter with nominal voltage level of 12V is selected.

The size of the battery required for the system is designed using (2) with assumption of Battery Loss Factor of 0.85 and Depth of Discharge of 0.6 as used in [5]. A 2 days Day of Autonomy is assumed

$$BatteryAh = \frac{Total\,Whr/day \times DOA}{Batterylossfactor \times DOD \times BatteryNominalVoltage} = \frac{1750 \times 2}{0.85 \times 0.6 \times 12} \approx 572Ah$$

Hence three units of 200Ah, 12V battery are selected to be connected in parallel.

With assumption of 95%, 95%, 80% and 95% efficiencies for cable, regulator, battery and inverter as well as PSH of 8 hours as used in [5]. The power required of the PV system using equation (3) is thus:

$$P_{PV} = \frac{E_L}{\eta_{out} \times \eta_{cable} \times \eta_{reg}} = \frac{1750}{0.8 \times 0.95 \times 0.95 \times 0.95} = 2551.39W,$$

Hence the Peak Power of the panel will be:

$$PVPeakPower = \frac{2318.12}{8} = 318.92W$$

A Monocrystalline module of input power 250W whose specifications at standard test condition of 1000W/m^2 and 25^{o}C is given in Table 2 is selected for the design. Then the number of panels required in parallel is:

$$N_p = \frac{318.92}{250} \approx 2$$

Using equation (7), the rating of the controller is:

$$\text{ControllerRating(A)} = N_{pp} \times 1.3 \times I_{sc}$$
$$= 2 \times 1.3 \times 8.75 = 22.75\text{A}$$

Hence a 30A, 12 V controller is chosen.

The summary of results for components sizing of the stand-alone Photovoltaic system is as presented in table 3.

Table 2: Properties of Selected Monocrystalline Photovoltaic Panel

S/No	Characteristic	Ratings
1	Maximum Power (Pmax)	250 W
2	Maximum Power Tolerance	±3%
3	Open Circuit Voltage (Voc)	37.6 V
4	Short Circuit Current (Isc)	8.75 A
5	Maximum Power Voltage (Vmp)	31.70 V
6	Maximum Power Current (Imp)	8.02 A
7	Maximum System Voltage	1000 V
8	Weight (W)	18 Kg

Table 3: Summary of Results for Components Sizing

S/No	Component	Quantity	Specification
1	Inverter	1	1KVA, 12V, 50Hz
2	Battery	3	12V, 200AH to be connected in Parallel
3	PV Module	2	250W each to be connected in parallel
4	Charge Controller	1	12V, 30A MPPT

Cost Analysis

The Life Cycle Cost analysis of the designed stand-alone PV system for a barbing saloon is compared with that of gasoline powered generator (TEC 1kVA/0.8kW SMALLIE 1000 type) whose specification is as given in table 4. The details of cost data surveyed as at December 2019 and used are presented in tables 5 and 6 with assumption of installation Cost of 10% of PV cost and Operation and Maintenance Cost of 2% of PV cost. The barbing Salon is believed to be on for Seven days in a week for fifty-two weeks in a year.

Table 4: Specification of the Gasoline Generator

S/No	Performance	Specification
1	Max Power Output	900W
2	Voltage	230V
3	Current	3.5A
4	Fuel Consumption	0.96Lt/kWhr
5	Power Factor	1
6	Noise level	68dB
7	Frequency	50Hz

Table 5: Cost Data Table for PV System Components

S/No	Component	Cost (₦)
1	1 KVA Inverter	55,000
2	200Ah 12V Battery	75,000
3	250W 12V PV Module	50,000
4	30A/12V Charge Controller	15,000
5	Installation Cost	5,000

	(10% of PV Cost)	
6	Operation and Maintenance Cost per year (2% of PV Cost)	1,000

Table 6: Cost Data Table for Gasoline Generator

S/No	Component	Cost (₦)
1	1 KVA 220V,50Hz Gasoline Generator	60,000
2	Fueling @ 0.96Lt per 1kWhr per day (476.24 liters per year @ 145 Naira)	69,054.34
3	Operation and Maintenance Cost per year	15,000

With a discount rate of 4.25%, inflation rate of 3% and life span of 5 years using equation (12b):

$\beta = \left(\frac{1+i}{1+d}\right) = \left(\frac{1+0.03}{1+0.0425}\right) = 0.9880$; this value of β was used to get the cumulative present worth factor using equation (15);

$$CPW_f = \frac{1-\beta^n}{1-\beta} = \frac{1-0.9880^5}{1-0.9880} = 4.8814$$

With this cumulative present worth factor, the present worth value after lifetime of five years for fueling of the gasoline generator as well as that of operation and maintenance was determined. The results obtained is as presented in tables 7 and 8.

Table 7: Result of Life Cycle Cost Analysis for the Designed Solar PV System

S/No	Component	Cost at First Year (₦)	Present Worth(₦)
1	1 KVA Inverter	55,000	55,000
2	200Ah 12V Battery	225,000	225,000
3	250W 12V PV Module	100,000	100,000
4	30A/12V Charge Controller	15,000	15,000
5	Installation Cost (10% of PV Cost)	5,000	5,000
6	Operation and Maintenance Cost per year (2% of PV Cost)	1,000	4,881.4
	Total		**404,881.4**

Table 8: Result of Life Cycle Cost Analysis for the Gasoline Powered Generator

S/No	Component	Cost (₦)	Present Worth(₦)
1	1 KVA 220V,50Hz Gasoline Generator	60,000	60,000
2	Fueling @ 0.96Lt per 1kWhr per day (557.14 liters per year @ 145 Naira)	80,784.72	394,342.53
3	Operation and Maintenance Cost per year	15,000	73,221
	Total		**527,563.53**

From the foregoing, the initial cost of Solar PV system is high while that of the gasoline power generator is fairly affordable. However, the life cycle cost analysis of solar PV system is lower than that of generator implying that at the end of 5 years life span, the Solar PV system would have saved ₦122,682.13. Aside from amount saved, Solar PV system is noiseless, doesn't emit carbon monoxide like gasoline and the cost of maintenance is extremely cheaper than that of gasoline powered generating set.

V. CONCLUSION

The design of a Stand-Alone Solar PV system for a SME-Barbing Saloon, has been considered and reported in this work. The design with load estimate of 409W arrived at 1kVA inverter, three units of 200Ah, two units of 250W solar panel and 30A, 12V charge controller. Life cycle cost analysis was carried out for the system and compared with a 1kVA gasoline generator to ascertain which is more economical. It was found out that aside from other benefits associated Solar

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PV system, it is more economical than gasoline generator.

Though the initial cost of the Solar PV system is high, in the long run it saves money and as such it is recommended for barbing saloon in Nigeria.

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